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INVESTIGATION OF
COATING SYSTEMS AND REMOVERS
FOR
GRAPHITE/EPOXY COMPOSITE SURFACES

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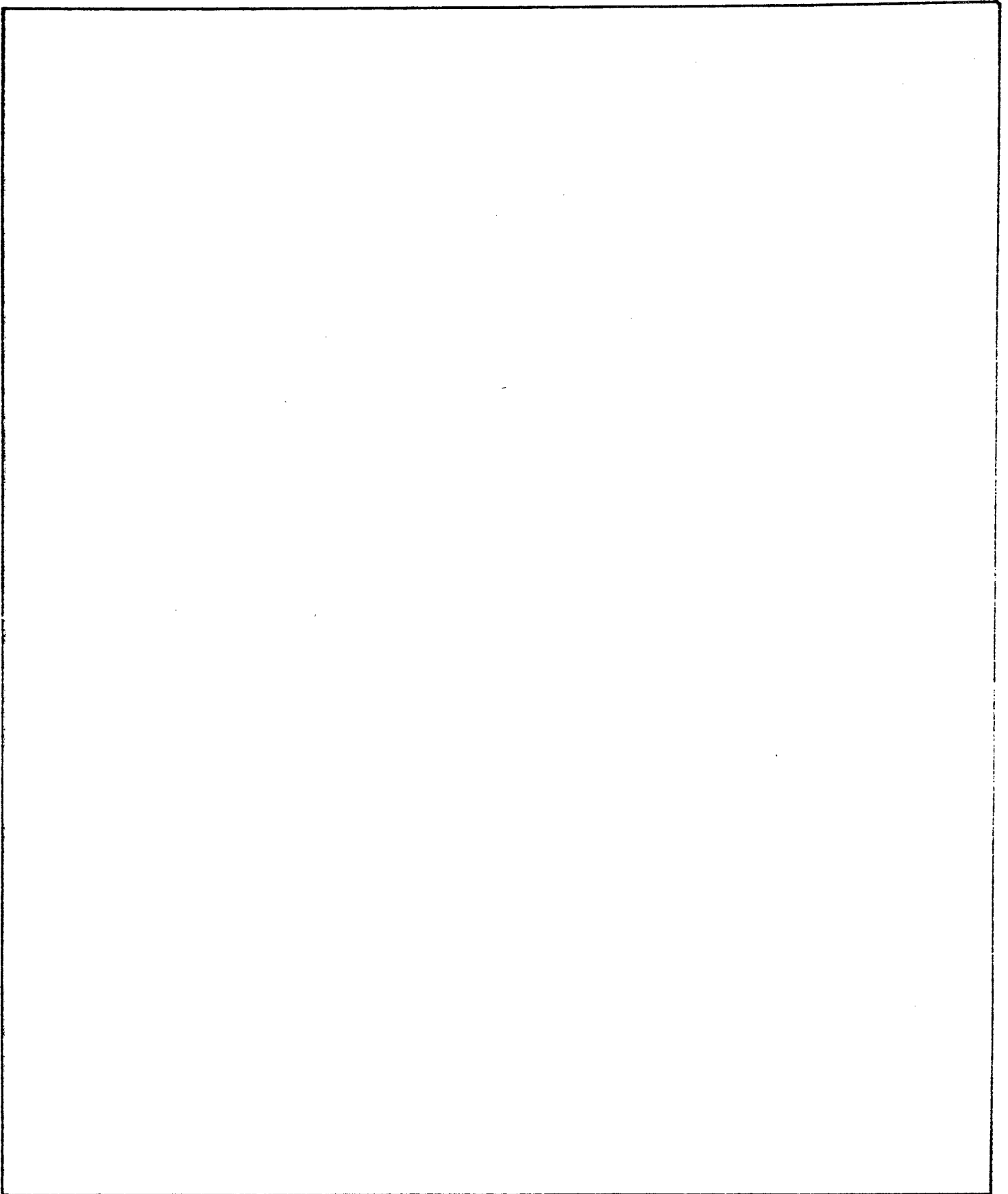
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SUMMARY

INTRODUCTION

The F/A-18 and A/V-8B represent the first major deviation from the all-aluminum skin aircraft by introducing extensive amounts of graphite/epoxy composite material. Since the epoxy matrix is a high temperature curing polymer with high crosslink density, it resists attack by many organic solvents without swelling or dissolution. In fact, composite specimens do not show visible evidence of attack when exposed to epoxy paint removers for as much as several days. However, such removers contain certain activators which will cause degradative effects when residues accumulate in the epoxy matrix. The objective of this investigation is the development of a coating system and remover combination that is compatible with the Hercules AS/3501-6 graphite epoxy composite as well as conventional aluminum skins.

Two types of coating systems were investigated:

- 1) Permanent primer systems
- 2) Strippable primer systems

Conventional epoxy removers, in-house formulations for composite compatible removers, and proprietary removers were investigated.

RESULTS

All "permanent" primers evaluated, with the exception of MMS-425 epoxy primer, were easily removed from aluminum panels with aged chromate conversion coatings when exposed to conventional epoxy paint strippers. Even treatments designed to artificially age painted test panels failed to produce a permanent coating. The MMS-425 epoxy primer was the only coating tested which showed some resistance to removers; however, after exposure to an epoxy compatible remover, the coating was quite soft and easily scratched through to bare substrate.

Two strippable coating systems were devised by first identifying removers compatible with Hercules AS/3501-6 graphite/epoxy composite, then identifying coatings which could be stripped with those removers. Using two test methods, a wedge crack extension test and a residual tensile strength test, three removers were found to be reasonably compatible -- methylene chloride, a thixotropic methylene chloride/ethanol remover, and a proprietary polysulfide remover. These tests also indicated that methanol, ammonia and phenol (activators which are useful in removing epoxy coatings) could not be used without reducing the tensile strength of exposed graphite/epoxy specimens. Additional compatibility

tests indicated that methylene chloride based removers produced significant strength losses in FM-300 adhesive.

Of the four strippable primers investigated, only TT-L-32 nitrocellulose lacquer and MIL-S-81733 polysulfide spray sealant could be stripped easily with epoxy compatible removers. While TT-L-32 could be used as a release coating on graphite/epoxy composite surfaces, it exhibits marginal adhesion on metallic surfaces, poor flexibility after aging, and lacks corrosion inhibiting pigments. If the lacquer were to be used as a release coating on graphite/epoxy surfaces, it would be necessary to treat the composite surfaces separately, during both the painting and stripping processes. The polysulfide spray sealant (MIL-S-81733) system exhibited excellent removability using existing polysulfide removers. However, such removers could seriously depolymerize sealant around fasteners on wet wing aircraft.

CONCLUSIONS

Amine-cured epoxy primers are not completely permanent. Partial removal and softening can be expected even with an epoxy compatible lacquer remover. In addition to phenol and amine activators contained in MIL-R-81294 removers and acid activators in MIL-R-81903, methanol and ammonia can be harmful to graphite/epoxy composites.

TT-L-32 nitrocellulose lacquer can be used on graphite/epoxy composites but not on metallic surfaces. Use of this release coating would necessitate separate treatment of metallic and composite surfaces and require extensive masking. The polysulfide system could be used on both surfaces but could pose a problem during paint removal if polysulfide removers seriously depolymerize sealant around fasteners on wet wing aircraft. Removers compatible with graphite/epoxy have been found for both systems, however, even these removers are not compatible with FM-300 adhesive.

RECOMMENDATIONS

The extent to which fastener seals are affected by polysulfide removers should be investigated using specific F/A-18 and A/V-8B configurations. Using this study and experience at NARF Alameda with polysulfide coating systems, it should be possible to evaluate the potential of this strippable system.

As an alternative to chemical paint removal, the rapidly developing plastic particle blasting technology should be investigated for removal of coatings from graphite/epoxy composite surfaces.

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BACKGROUND

In an initial investigation into the effects of maintenance chemicals on graphite/epoxy composites, it was reported in reference (a) that paint removers could produce irreversible strength losses when allowed to remain in contact with the composite surfaces for prolonged time periods or at elevated temperatures. While no obvious visual evidence forewarned of this effect, such losses clearly indicated a lack of chemical compatibility. It was also reported that a nitrocellulose lacquer could be used as a release coating when stripping with a less aggressive paint remover formulation. In an effort to develop the concept of chemically compatible paint removers for the Hercules AS/3501-6 composite system, alternative coating systems and compatible removers were studied.

Several strategies were developed with the following lines of reasoning:

- 1) Permanent primer. If the base coat of primer (that coating in direct contact with the composite surface) were permanent, it might act as a barrier to paint remover diffusing toward the composite while allowing the removal of coatings directly above it. Such a system might not require the use of compatible removers.
- 2) Strippable primer. If a coating could be removed using compatible removers, it would function as a "weak link" in the coating system. Stripping this primer would also strip any overcoatings.

The remainder of this report discusses such coating systems, different types of removers, and methods for evaluation of compatibility with graphite/epoxy.

PERMANENT PRIMER SYSTEMS

The permanent primer concept is certainly not new. When F-4 and later A/V-8A aircraft were first stripped during rework operations, the amine-cured primer coatings could not be removed using the conventional MIL-R-81294 epoxy paint removers. As a result, an acid paint remover specification MIL-R-81903 was developed which is still used to remove stubborn patches of conventional polyamide-cured epoxy as well as the more resistant amine-cured coatings. The effectiveness of acid removers was apparent in the work reported in reference (a) when such removers produced rapid delamination and digestion of the composite matrix under test.

Initial Evaluation

Since permanent or chemically resistant primers should remain intact during the paint stripping process, standard primers as well as some "weak link" coatings were included as intermediate coatings in the initial study.

The candidate permanent primers were:

- 1) DeSoto Super Koropon 513X003/910X014
- 2) DeSoto Fuel Tank Primer (MIL-C-27725) 823X011/910X099
- 3) Imperial Epoxy Primer F580-2010/F273-5076.

The candidate intermediate coatings were:

- 1) Epoxy-polyamide Primer (MIL-P-23377)
- 2) Deft Water-borne Epoxy Primer 44-GN-7 (MIL-P-85582)
- 3) DeSoto Koroflex 823X367
- 4) Wash Primer (MIL-P-8514)
- 5) Nitrocellulose Lacquer (TT-L-32).

The topcoats used were:

- 1) Low IR Polyurethane (MIL-C-85285)
- 2) Gloss White Polyurethane (MIL-C-83286).

All combinations of these coatings, as well as the six binary systems prepared using the three permanent primers and two

topcoats, were sprayed on clad 2024 aluminum alloy panels, which had been treated with chromate conversion coating (MIL-C-81706), and anodized 0-temper 2024 aluminum alloy panels. The painted test panels were then dried at room temperature for seven days and further dried at 150°F for seven days.

Stripping tests were then performed using a qualified phenolic epoxy paint remover (MIL-R-81294, Type I) on those panels requiring an aggressive remover to lift the intermediate coating and a lacquer remover (TT-R-248) on panels with a lacquer or wash primer intermediate coating. Paint remover was applied to each test panel on a 60° test rack for 20 minutes, then brushed and rinsed under running tap water. The area percentage of the overcoats removed and the area percentage of the primer removed were estimated and the results listed in Table I. All coating systems were tested for impact flexibility using a GE Impact Tester. Selected systems were tested for wet tape adhesion after a 24-hour immersion in distilled water at 100°F. Results are listed in Table I.

Although coating systems using the wash primer and nitrocellulose lacquer appeared to be permanent when stripped with the "milder" TT-R-248 remover, small amounts of the primer were removed in the abnormally short stripping process. Since none of the coatings previously considered permanent were unaffected by the removers, it was proposed that the artificial aging process of one week at 150°F was insufficient for duplicating in-service aging. A second phase of this work was a study of various aging conditions.

Artificial Aging of Permanent Primers

In order to promote bonding to the substrate and maximum curing, six conditions were chosen to simulate aging of paint films using combinations of heat and humidity, salt fog and thermal cycling:

- 1) Control (Room temperature/Relative humidity 0%)
- 2) Humidity (Room temperature/Relative humidity 85%)
- 3) Heat (160°F/Relative humidity 0%)
- 4) Heat and humidity (160°F/Relative humidity 85%)
- 5) Salt fog exposure (95°F)
- 6) Thermal cycling (Room temperature 16 hours/160°F 8 hours)

Although baking temperatures above 250°F are known to affect

Table I
PERMANENT PRIMER SYSTEMS

<u>Base Coat</u>	<u>Inter-mediate Coat</u>	<u>Top-Coat</u>	<u>Coating Base Coat (%)</u>	<u>Removal Over Coats (%)</u>	<u>Flexibility (% elongation)</u>	<u>Adhesion</u>
Stripped with MIL-R-81294 *****						
1	1	1	70	100	20	
1	1	2	100	100	40	
1	2	1	90	100	<20	
1	2	2	100	100	40	
1	3	1	85	85	40	
1	3	2	95	95	60	
2	1	1	20	99	<20	
2	1	2	5	99	20	
2	2	1	20	97	<20	
2	2	2	1	20	<20	
2	3	1	95	100	<20	
2	3	2	3	3	40	
3	1	1	99	100	20	
3	1	2	80	85	40	
3	2	1	100	100	20	
3	2	2	40	90	40	
3	3	1	99	100	60	
3	3	2	60	99	60	
1	-	1	100	100	20	
1	-	2	30	30	40	
2	-	1	10	100	<20	
2	-	2	20	90	20	
3	-	1	95	95	60	
3	-	2	90	90	60	
Stripped with TT-R-248 *****						
1	4	1	0	100	20	Pass
1	4	2	0	100	40	Pass
1	5	1	0	0	<20	Pass
1	5	2	3	3	40	Pass
2	4	1	0	100	20	Fail
2	4	2	0	15	40	Fail
2	5	1	3	10	<20	Marginal
2	5	2	5	5	40	Pass

primer permanence, such conditions are not representative of the service environment.

Test panels for this test were chromate conversion coated, 7075-T6 aluminum alloy. Three sets of panels were prepared for exposure using the Imperial Epoxy Primer F580-2010/F273-5076:

- 1) Primer only
- 2) Primed; dried for 4 hours at ambient conditions; topcoated
- 3) Primed; dried for 24 hours at ambient conditions; topcoated

Artificially aged panels were tested after 1, 3, and 6 weeks of exposure by applying MIL-R-81294, Type I epoxy paint remover for 20 minutes as before. Results are shown in Table II.

Although the combination of heat and humidity appeared to have a significant effect on the permanence of the base coat, again, the primer even when exposed to various accelerated aging conditions could not be considered permanent.

Mechanical Surface Treatment and Primer Permanence

In an attempt to improve the permanence of amine-cured primer coatings, several mechanical treatments were used to condition both untreated and previously chromate conversion coated 7075-T6 bare aluminum alloy test panels prior to application of fresh chromate conversion coating:

- 1) Control - No treatment
- 2) Flap brush (3M Scotchbrite Fine Abrasive Mat) driven with an air motor
- 3) Hand abrasion using very fine abrasive mat
- 4) Lapping paper.

All test panels were subsequently solvent wiped with acetone, rinsed in deionized water, conversion coated, dried overnight, and painted with Imperial Epoxy Primer F580-2010/F273-5076 and gloss white polyurethane topcoat (MIL-C-83286). Following one week of air drying, some test panels were baked at 140°F for an additional week, others at 180°F. Stripping tests were performed using MIL-R-81294, Type I for 10 minute exposures on three replicate panels.

Table II
STRIPPING OF ARTIFICIALLY AGED PRIMER

Test Panels	Percent of base coat removed after exposure to					
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
Aged 1 week						
Primer only	100	100	95	90	40	50
Topcoat (4 hr)	95	95	100	95	95	95
Topcoat (24 hr)						
Aged 3 weeks						
Primer only	100	100	98	63	85	95
Topcoat (4 hr)	66	93	100	42	98	100
Topcoat (24 hr)	40	73	100	80	98	100
Aged 6 weeks						
Primer only	100	100	100	98	65	98
Topcoat (4 hr)	60	99	100	20	98	100
Topcoat (24 hr)	35	75	100	15	95	100

With the exception of the untreated control test panels, the results shown in Table III are discouraging. Mechanical treatment did not appear to have a significant positive effect in improving permanence.

Table III
EFFECT OF MECHANICAL TREATMENT
ON PRIMER PERMANENCE

<u>Test Panels</u>	Percent of base coat removed after baking at		
	<u>72° F</u>	<u>140° F</u>	<u>180° F</u>
Untreated 7075-T6			
Control	100	4	1
Flap brush	100	99	95
Hand abrasion	100	99	99
Lapping paper	100	100	100
Chromated 7075-T6			
Control	100	100	100
Flap brush	100	85	60
Hand abrasion	100	85	60
Lapping paper	100	85	100
Anodized 7075-T6	100	85	100

STRIPPABLE PRIMER SYSTEMS

The development of strippable primer systems depends on the difference between polymer sensitivities to activators or solvents present in the remover formulation. Since epoxy primers cannot be removed with solvents alone, epoxy activators must be used to break chemical bonds in the primer. Chemical removal of these primers from epoxy composite substrates would then simultaneously expose the composite matrix to agents designed to produce epoxy degradation. Certainly the best approach to designing strippable systems would be to choose non-epoxy primers which could be stripped due to a special chemical sensitivity not found in epoxy composites.

Initial Evaluation

Four candidate strippable primers were investigated:

- 1) Wash Primer based on a polyvinyl butyral resin (MIL-P-8514)
- 2) Nitrocellulose Lacquer (TT-L-32)
- 3) DeSoto Koroflex Polyurethane Primer 823X367
- 4) Polysulfide Spray Sealant (MIL-S-81733).

The first two primers contain binders known to be sensitive to methylene chloride, the solvent base of most chemical removers. The polyurethane primer is known to be sensitive to furfuryl alcohol, and the polysulfide primer is known to be depolymerized by mercaptans.

Test panels were prepared using both conversion coated aluminum and graphite/epoxy composite, primed with one or more of the above strippable coatings and topcoated with one of the following:

- 1) Low IR Polyurethane (MIL-C-85285)
- 2) Gloss White Polyurethane (MIL-C-83286).

Nitrocellulose lacquer was not applied directly to aluminum substrates since the adhesion of this coating was known to be marginal.

Results listed in Table IV were achieved with a 20 minute exposure to TT-R-248 for systems with primers 1, 2, and 3 and a 30 minute exposure to Cee-Bee A-458 (McGean-Rohco, Inc.) for systems with primer 4. Although the wash primer exhibited good adhesion, reference (b) indicates that such coatings should not be applied

Table IV
STRIPPABLE PRIMER SYSTEMS

<u>Base Coat</u>	<u>Inter- mediate Coat</u>	<u>Top- Coat</u>	<u>Coating Removal Base Coat (%)</u>	<u>Removal Over Coat (%)</u>	<u>Flexibility (% elonga- tion)</u>	<u>Adhesion</u>
7075-T6 Aluminum Test Panels *****						
1	-	1	100	100	40	Pass
1	-	2	100	100	60	Marginal
1	3	1	100	100	60	Pass
1	3	2	100	100	60	Pass
3	-	1	100	100	60	Pass
3	-	2	100	100	60	Pass
4	-	1	100	100	60	Pass
4	-	2	100	100	60	Pass
Graphite/epoxy Test Panels *****						
1	-	1	0	0	-	
1	-	2	0	0	-	
2	-	1	100	100	-	
2	-	2	100	100	-	
3	-	1	5	5	-	
3	-	2	10	10	-	
4	-	1	100	100	-	
4	-	2	100	100	-	

to chromate conversion coatings. It is believed that phosphoric acid used in the primer reduces some of the chromium in the conversion coating from the +6 to the +3 oxidation state. Further, the wash primer system could not be stripped from the composite substrate with the mild lacquer paint remover. DeSoto's Koroflex primer was also unstrippable with this remover. Nitrocellulose lacquer, however, could be stripped from graphite/epoxy surfaces, as was previously found in reference (a). This coating when used on graphite/epoxy and the polysulfide spray sealant, when used on any substrates and removed with mercaptan-activated strippers, proved to be strippable primers.

Development and Testing of Compatible Removers

Since TT-R-248 (which is a performance specification lacquer stripper) did prove effective on the nitrocellulose lacquer, the development of a compatible lacquer stripper should be feasible. The formulation of simple removers, such as a lacquer stripper, can be straightforward. Methylene chloride is the diffusing solvent which partially dissolves and swells the lacquer film, while also carrying polar components such as water, an alcohol, or a surfactant to the substrate bond to aid the release of the coating. Paraffin is used to minimize the rate of evaporation of methylene chloride into the atmosphere and is usually added as a solution in toluene. The best thickeners are derivatives of cellulose which require an alcohol for solvation and formation of the gel structure which provides the thixotropy. To facilitate rinsing and inhibit corrosion, surfactants are often used. Finally, activators such as ammonia or methanol are often added. In the preparation of removers for epoxy primers, other activators such as phenol, cresol, amines, formic acid or hydroxyacetic acid might be used.

In order to determine chemical compatibility of paint removers with graphite/epoxy composite substrates, two methods were used. The first was one which accelerated any chemical reaction which might occur in an unstressed substrate-remover system. The second method measures the rate of crack growth in a wedge crack specimen during immersion in the paint remover.

- 1) Pressure bottle test. Matrix-dominated graphite/epoxy tensile specimens (8-ply: +45,-45,+45,-45,-45,+45,-45,+45) were inserted into a pressure bottle containing the remover to be tested for compatibility. The bottle was capped and placed in a 160°F oven for 7 days. At the end of the exposure period, the bottle was cooled slowly to room temperature and the specimens removed and dried at 160°F for an additional 7 days. Five replicates were tested for residual tensile strength at room temperature. Significant

strength losses indicate chemical incompatibility.

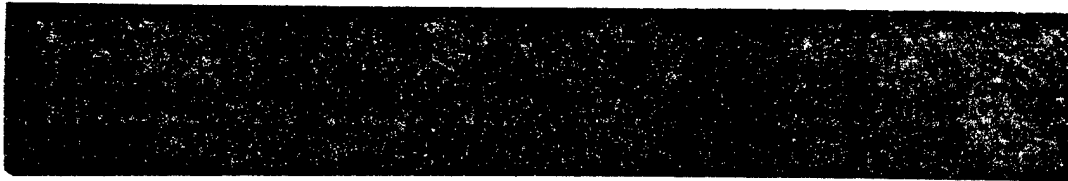
- 2) Crack growth test. Graphite/epoxy composite laminates (50-ply: were cut into one inch by six inch specimens (see Figure 1). During the layup of the laminate, a 0.001 inch thick strip of Tedlar was incorporated between the 25th and 26th plies such that each specimen, when cut, would have a one square inch section of Tedlar at one end to facilitate crack initiation. A sharp steel wedge 0.125 inch thick was driven into the end of a specimen one hour prior to paint remover exposure. After measuring the initial crack length, the specimen was immersed in a jar of paint remover and placed in an oven at 95°F. Periodically, the growth of the crack was measured, until after one week of exposure, the specimen was rinsed thoroughly and subjected to 100 percent relative humidity at 140°F for an additional week. Crack growth was then plotted as a function of time.

Table V lists results of the pressure bottle test for methylene chloride, MIL-R-81294 phenolic remover, and several in-house formulations. Surprisingly, methylene chloride showed little effect on tensile strength, while the phenolic remover caused almost complete delamination. Previous work with non-phenolic removers in reference (a) found strength losses in the 30 to 50 percent range using a similar test. From in-house formulations R-7, R-7A, R-7N and R-7AN (shown in Table VI) it was found that ammonia and methanol produced strength losses which are additive when both are present in the formulation. A furfuryl alcohol formulation, R-8FA, was prepared specifically for removal of the Koroflex polyurethane primer. However, even various modifications to this formula using water and ethanol to vary the solubility characteristics of the remover, did not improve the removability of the coating from graphite/epoxy.

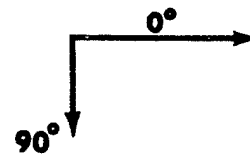
Further evaluation of these removers for compatibility using the crack growth test resulted in the plot in Figure 2. Each curve was plotted using average crack growths of 4 replicates measured at 1, 24, 48, 120, and 192 hours during the remover exposure and after an additional 168 hours at 140°F and 100 percent relative humidity. The phenolic epoxy remover (MIL-R-81294, Type I) exhibited rapid crack growth roughly proportional to the square root of the exposure time, while the non-phenolic (Type II) produced rapid crack growth in the first 24 hours which then quickly diminished. Interestingly, the specimens exposed to the phenolic remover continued to show significant crack growth after remover exposure. Control specimens exposed to air and water under the same conditions did not show significant growth, and a similar methylene chloride exposure produced only slight crack extension.

The small crack growth in methylene chloride was encouraging for

TOP VIEW



LAMINATE REFERENCE DIRECTION



SIDE VIEW



50 PLY AS/3501-6 GRAPHITE/EPOXY COMPOSITE MATERIAL

FIGURE 1. WEDGE CRACK GROWTH SPECIMEN

Table V
PRESSURE BOTTLE TEST RESULTS

Paint remover	Tensile strength loss (percent)
Methylene chloride	3.0
MIL-R-81294, Type I	DELAMINATION
Formula R-7AN (ammonia, methanol)	31.8
Formula R-7 (ammonia, ethanol)	25.7
Formula R-7A (methanol)	13.8
Formula R-7 (ethanol)	5.9
Formula R-8FA (furfuryl alcohol)	13.0
Cee-Bee A-458	2.5

Table VI
REMOVER FORMULATIONS

Component	Formula Designation				
	<u>R-7</u>	<u>R-7A</u>	<u>R-7N</u>	<u>R-7AN</u>	<u>R-8FA</u>
Methylene chloride	76.2	76.2	76.2	76.2	76.2
Paraffin	1.7	1.7	1.7	1.7	1.7
Toluene	2.4	2.4	2.4	2.4	2.4
Methocel F4M-PRG (1)	1.6	1.55	1.6	1.55	1.2
Ethanol	7.3	--	7.3	--	--
Methanol	--	7.3	--	7.3	--
Potassium oleate (2)	6.9	6.9	6.9	6.9	6.9
Ammonia (28 percent)	--	--	3.9	3.9	--
Furfuryl alcohol	--	--	--	--	7.6

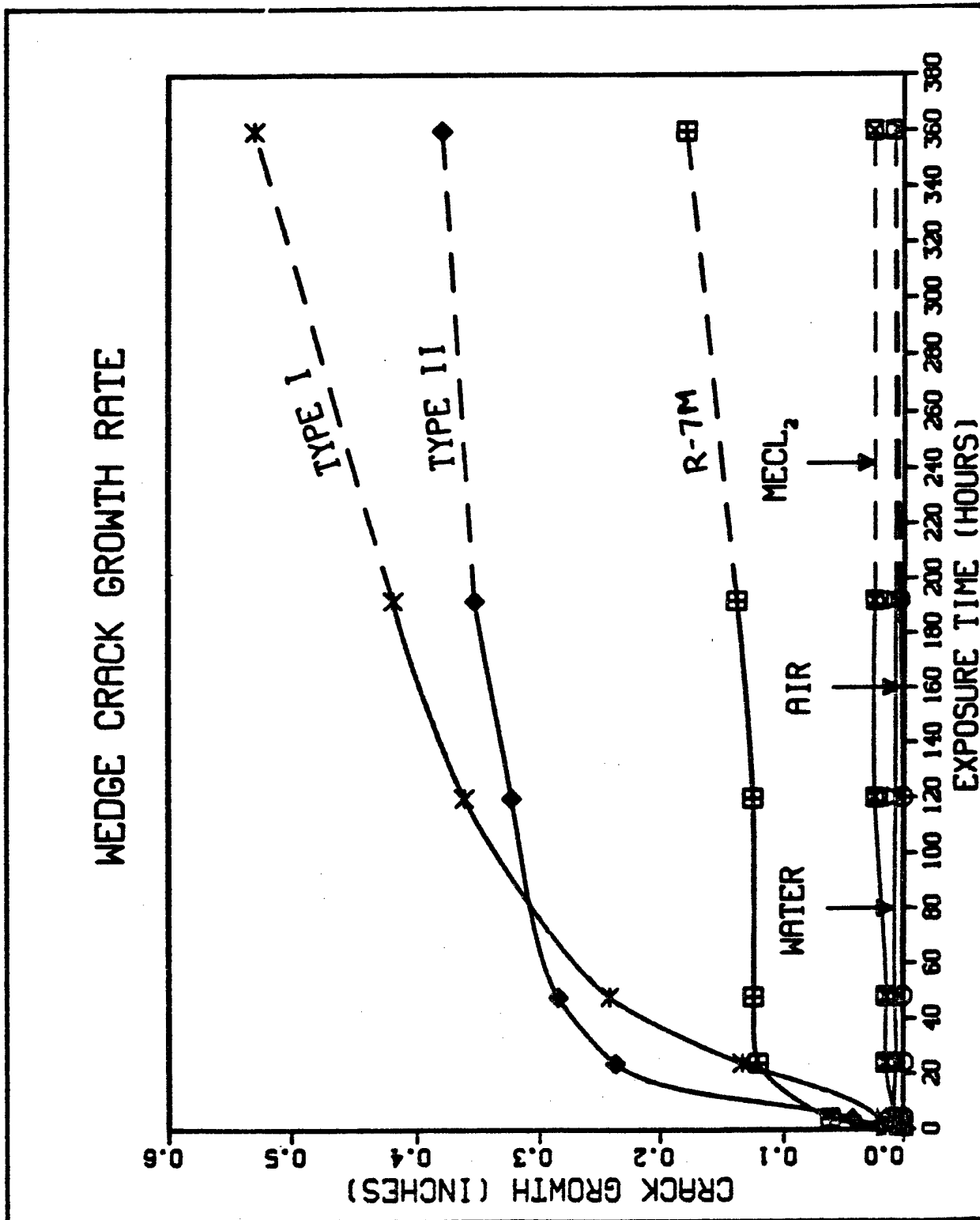


Figure 2. Crack Propagation in Wedge Crack Specimens Immersed in Several Paint Removers, Air and Water

the development of a compatible remover, but further crack growth measurements to determine the effect of the cosolvent used to solvate the thickener showed significant crack extension. Methanol and ammonia were dropped from testing in the crack propagation experiments due to poor compatibility in the pressure bottle test. Ethanol and propylene glycol in 10 percent solutions with methylene chloride caused growths of 0.23 and 0.32 inches, respectively, after a one week exposure. Formulation R-7M prepared using ethanol, the least harmful cosolvent, produced some initial crack growth which continued only at a very slow rate after 24 hours (as compared to MIL-R-81294). R-7M is essentially the same as R-7, differing only by a small quantity of thickener. The polysulfide remover Cee-Bee A458 (not shown) produced a crack growth curve nearly identical to R-7.

Finally, the effect of two removers and methylene chloride was determined on American Cyanamid FM-300 adhesive using clad 2024-T3 aluminum lap shear specimens. Adherends were treated with FPL (Forrest Products Laboratory) etch, primed with American Cyanamid BR-127 and bonded with FM-300 adhesive using a one hour cure at 350°F and 50 psi pressure. After immersion in the test fluids for one week at 95°F followed by drying in air at 95°F for an additional week, nine replicates were tested for residual tensile strength. Results shown in Table VII indicate that even methylene chloride reduced the shear strength of the adhesive. Formulation R-7M produced nearly the same effect, while the phenolic remover (MIL-R-81294, Type I) caused double the strength loss of R-7M. Additional work with adhesively bonded wedge crack specimens, using 0.125 inch thick aluminum adherends prepared using the same procedures as the lap shear specimens, appeared to yield data similar to graphite/epoxy crack growth specimens. However, due to adhesive swelling and subsequent cracking at the edges, the crack growth measurements could not be made accurately.

In summary, R-7M and Cee-Bee A-458 were the most compatible removers tested. Since the A-458 stripper proved adequate for polysulfide removal on both aluminum and graphite epoxy substrates, further work centered on a coating system incorporating the nitrocellulose lacquer (TT-L-32) release coating.

Strippable system using TT-L-32

Using another permanent primer candidate base coating, McDonnell Douglas MMS-425 primer, the following coating system was prepared:

Primer	- MMS-425 Epoxy primer
Release coat	- TT-L-32 Nitrocellulose lacquer
Topcoat	- MIL-C-83286 Polyurethane

Table VII
EFFECT OF REMOVERS ON FM-300
LAP SHEAR STRENGTH

Paint remover	Average lap shear strength loss (percent)
Control (Air)	--
Methylene chloride	9.0
Formula R-7M	9.6
MIL-R-81294	20.8

The release coat was applied after the primer had been allowed to dry 4 hours on one set of chromate conversion coated test panels and after 24 hours on the second set. The topcoat was applied after the release coat had been allowed to dry for one hour. Panels were cured at room temperature for 7 days then baked at 150°F for an additional 7 days.

Using R-7M, the polyurethane topcoat and the nitrocellulose lacquer were stripped completely from the 4 hour panels but only partially from the 24 hour panels, and while no bare substrate was visible, a layer of the primer was removed in both cases. It was also noted that the primer was quite soft and could be scratched through to the substrate with a plastic scraper.

CONCLUSIONS

The "permanence" of coatings is not well understood. While the extent of cure of the primer coating is certainly important, substrate preparation and pretreatment may be the most critical factors in developing a resistance to paint removers. For example, table II demonstrated that the combination of heat and humidity is more important than heat alone for improving remover resistance; however, more remarkable is the effect of untreated, unabraded substrates as shown in table III. While this condition may be achieved on aircraft in production, aircraft undergoing rework are normally abraded to remove corrosion and have been previously pretreated. Even when a remover resistant bond to the substrate is achieved as with the MMS-425 base coat system, the primer is easily damaged and may not possess the durability required for prolonged deployment. For this reason, the permanent primer approach cannot be recommended.

In contrast, strippable coating systems for graphite/epoxy composites are feasible since the composite matrix is not significantly attacked by methylene chloride, the basic component for most removers. The two methods used to determine compatibility tested the resistance of graphite/epoxy to strength losses when exposed in stressed and unstressed conditions. While methylene chloride did not cause significant effects in either test, formulated removers did. Removers prepared with methanol and ammonia produced significant strength losses following the unstressed exposure and were therefore not tested in the wedge crack test. While two removers, R-7M and Cee-Bee A-458, exhibited compatibility based on the unstressed exposure test, crack growth rates significantly greater than that due to methylene chloride alone were noted in the wedge crack test, although these rates were much less than those of the MIL-R-81294 removers after one or two days of exposure. At this time, the importance of the wedge crack test is unknown; however, it can be concluded that formulations such as R-7M and A-458 are less harmful than MIL-R-81294 removers during long term exposure.

In view of the chemical compatibility of R-7M and A-458 with graphite/epoxy, two strippable systems are possible. In the coating system strippable with R-7M, graphite/epoxy substrates must be treated different from aluminum substrates:

	<u>Aluminum</u>	<u>Graphite/Epoxy</u>
Base coat	MIL-P-23377 (epoxy/polyamide primer)	TT-L-32 (nitrocellulose lacquer)
Topcoat	MIL-C-83286 or MIL-C-85285	MIL-C-83286 or MIL-C-85285

Composite substrates would have to be masked during the stripping of the epoxy primer/polyurethane topcoat from aluminum with a MIL-R-81294 epoxy remover, then the composite surfaces would be stripped using R-7M or a similar material. Likewise, masking would be required during painting to achieve the above paint systems. Such a process does not appear cost effective.

An alternative system, which would not require separate treatment of metallic and composite substrates, would make use of the chromate-inhibited polysulfide spray sealant MIL-S-81733 as the base coat and polyurethane topcoat. Such a system may require the use of an intermediate coating of MIL-P-23377 epoxy primer to guarantee adhesion and corrosion protection; however, this system has been used for several years at NARF Alameda. In addition, Cee-Bee A-458 has been field tested successfully for removal of this coating system. This system has the advantage of being one of the most flexible paint systems currently applied to aircraft. The only disadvantage of this approach is that polysulfide sealant is also used to seal wing fasteners. Attack at those points could result in leaks from wet wing aircraft (those without fuel cell bladders in the wings, such as F/A-18 and AV-8B).

It was determined that contamination of FM-300 adhesive with paint removers should be avoided due to loss of shear strength. Although MIL-R-81294 epoxy removers produced the largest strength losses, even a compatible remover and methylene chloride caused significant losses. This sensitivity of epoxy adhesives to methylene chloride is probably due to the use of an elastomeric component in the adhesive to improve toughness.

RECOMMENDATIONS

The extent to which fastener seals are affected by polysulfide removers should be investigated using specific F/A-18 and A/V-8B configurations. Using this study and experience at NARF Alameda with polysulfide coating systems, it should be possible to evaluate the potential of this strippable system.

As an alternative to chemical paint removal, the rapidly developing plastic particle blasting technology should be investigated for removal of coatings from graphite/epoxy composite surfaces.

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